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Mechanical Strengths and Permeability Properties of Porous Concrete of Aggregate Gradation in Energy Industry

[1]B. Venkati, [2]Dr. Manjula Vani K.

[1]Research Scholar, Department of Civil Engineering, JNTU Hyderabad, Telangana

[2]Professor, Department of Civil Engineering, JNTU Hyderabad, Telangana

***Abstract*:**

Porous concrete (PC) is a very popular construction material in developed countries and is now finding application in India in parking lots. In this investigation, an effort was made to study the various performances of PC in the laboratory. Different gradations of coarse aggregates namely 4.75–10 mm, 10–12.5 mm, and 12.5–16 mm is considered to characterize PC adopting conventional compaction by tamping rod, additional 5 and 10 compactions by proctor hammer. The effect of varying compaction and the coarse aggregate gradation is studied on axial compressive, flexural tensile, and splitting tensile strengths of PC. In addition, a simple method is proposed to determine the permeability of all PC mixes. The work was extended to know the influence of low-grade fly ash and GGBS as supplementary cementing materials (SCMs) on the strengths and permeability of PC. Though the strength of PC in the presence of SCMs has decreased, the permeability and the estimated porosity of all mixes decreased compared to the 100% cement counterpart.

Keywords: *Concrete, SCM, porosity, Pervious concrete, permeability, fly ash, hydraulic properties, Energy Industry.*

1.0 Introduction:

Porous concrete (PC) or permeable concrete is a construction material with a high volume of interconnected voids. The first application of the PC was in 1852 [1] and is receiving renewed interest nowadays. The PC is a distinct mixture of cement, high-performance additives, and coarse aggregate (CA). This concrete mixture consists of a lower fraction of fine aggregates (FA) or no fine aggregates, creating a considerable amount of void content. The lower fraction FA or mortar content in PC leads to high porosity, which eventually leads to low-strength concrete. The highly permeable, interconnected voids in PC allow water to flow quickly through the concrete matrix [2, 3]. The flow of water through the voids aids in filtering water, thus hindering the penetrability of chemicals and hazardous contaminants entering the soil. The permeability coefficient of PC varies from 2 to 10 mm/s and porosity varies from 15 to 25% [4, 5]. Hence it is gaining attention as an eco-friendly, lightweight, and sustainable potential green material in the research and construction industry [6]. In addition to higher porosity, PC has energy-efficient properties like low thermal conductivity and higher sound insulation [4]. PC has been used in building road pavements, sidewalks, parks, and building exteriors due to its porous nature [7]. The higher permeability coefficient of PC also aids in enhancing groundwater potential and reducing storm-water runoff [8]. However, its usage in India is rather limited and is in the early stages of application.

Industrial byproducts such as fly ash (FA), ground granulated blast furnace slag (GGBS), and lightweight aggregates are used in the production of conventional, geopolymer, and PC [9,10,11]. In addition, many unconventional aggregates derived from vitrified, ceramic, and cinder wastes have strong potential in the production of low-strength concretes and PC [12]. The type, shape, and size of the coarse aggregates play a significant role, in the strength development [13]. The low FA content leads to the thin film coating on the aggregates that affect the compressive strength of the PC, which ranges from 2.8 to 28 MPa. The main aspect of PC is the volume of voids/ porosity, size of voids, pore-network or interconnectivity of voids, and in-situ density of the fresh concrete. ASTM C1688 test method is used to find the fresh density (unit weight) of PC which 2200 ± 80 kg/m^3 is considered in the mix design.

Determining of permeability of a PC in a simple way is quite challenging. In this work, an attempt has been made to develop a simple and quick method to determine the permeability of the PC. In addition, several mechanical properties of PC, and permeability are also investigated to characterize its performance. Furthermore, the relative cost of the PC will be lower compared with the OPC. This is due to the absence of fine aggregates in the PC. The cost that is being spent for fine aggregates for 1 m^3 concrete production can be completely saved. With these objectives, current work is aimed at designing PC with varied fresh concrete density, mechanical properties, and permeability coefficient values. In practice generally, the fresh concrete density was varied by varying degrees of compaction. An in-house permeability apparatus was designed and built to measure the permeability coefficient of designed PC mixes. Industrial byproducts such as FA and GGBS are used as supplementary cementitious materials (SCM) at 50% replacement to ordinary Portland cement (OPC).

2.0 Methodology:

The influences of compaction and the coarse aggregate gradation were studied on the flexural, splitting tensile, and compressive strengths of PC. The permeability of PC is proposed by a simple test method and the results are quite satisfactory. An attempt was also made to utilize supplementary cementing materials as a replacement for cement.

3.0 Materials:

The materials considered in the study were, water, coarse aggregates, class F FA with a specific gravity of 2.1, and GGBS with a specific gravity of 2.91, OPC of 43 Grade satisfying the requirements of IS 269-2013. Table 1 shows the properties of 43-grade OPC used in the current study is tabulated. The hard granite coarse aggregate in three gradations namely, 4.75 to 10 mm, 10 mm to 12.5 mm, and 12.5 mm to 16 were used with 95% of OPC, 70% of FA, and 60% of GGBS passing through a 90-µm sieve. The FA and GGBS are relatively low grade with low pozzolanic used in this work. For the low pozzolanic, the compressive strength at 28 days is found to be 61% when tested as per IS 3812 (Part 1).

Table 1: Preliminary test results on OPC 43 grade cement

Description	Test value	Requirement of OPC (As per IS:269–2015	Method of test
Normal consistency (in %)	29.5	No standard value	IS:4031 part 4, 1988
Setting time (in minutes)			
i) Initial setting time	135	Not less than 30	IS:4031 part 5, 1988
ii) Final setting time	245	Not more than 600	
Specific gravity (Le-Chatelier's flask)	3.14		IS:4031 part 11, 1988

Description	Test value	Requirement of OPC (As per IS:269–2015	Method of test
Fineness, % (dry sieving)	6.2	Not more than 10	IS:4031 part 1, 1996
Fineness by Blain's air permeability method (m^2/kg)	275	Not less than 225	IS:4031 part 2, 1999
Soundness (Le Chatelier's method), mm	0.5	Not more than 10	IS:4031 part 3, 1988
Compression strength (MPa)			
3 days	25.48	23	IS:4031 part 6, 1988
7 days	37.67	33	
28 days	46.58	43	

3.0 Experimental program:

Mix proportions for PC

Different mix proportions are suggested by different investigators. The typical mix proportions for PC as suggested in ACI 522R10followed. The mix design employed is presented in Table 2. Suitable combinations of supplementary materials are used. Additional compaction by the modified Proctor hammer is was provided to modify the properties of concrete. Initially, the concrete is was compacted a with tamping rod and later compacted by giving 5 and 10 additional blows over an area of 100 × 100 mm. Generally, the PC water-cement ratio was found to vary from 0.24 to 0.42 and the aggregate-to-cement ratio varies from 3.97 to 6.50. In the present study, these values are 0.35 and 3.5 respectively.

Results and Discussions:

Compressive strength:

Among the three conventional mixes PV1, PV2 and PV3, PV3 achieved the highest compressive strength. Fig.1(a) depicts the effect of fly ash on the PV1 mix. With the rise of fly ash in cement content, the strength of pervious concrete also enhanced. PV1F20 attained18.53MPa compressive strength at 28 days curing period, which was about 14.1% compared to reference mix PV1. However, at the maximum replacement level of cement attained the similar results to the conventional mix. At 5%, 10%, 15%, 20%, 25% and 30% FA content incementhas16.81MPa,17.36MPa,18.04MPa,18.53MPa,17.31MPaand16.43MPa

respectively. Fig.1(b) presents the pervious concrete compressive strength results for PV2 mix with and without FA in cement at different levels. In this mix, the aggregate size with 12.5-10mmenhanced the strength parameters than the aggregate mix with 16.5-12mm. Approximately,5% strength has been enhanced with lower sized aggregates. With the help of FA in the cement increased about 18% compressive strength than the conventional mix. The change in strength varied from 4% to 18% with increase of FA up to 20%. Beyond 20% FA, the trend reversed and ended above the reference mix. Fig.1(c) showed the results of PV3 mix. It was observed that the maximum strength has attained in this mix only, even without FA in the cement. It may be due to the reduction of voids by decreasing aggregate size. FA paly additional advantage by pozzolanic action with cement. Similar trends were observed in thePV3 mix with FA. About 13% strength was augmented with the 20% FA. 13% strength development is lower than PV2andPV1mix but, the magnitude is higher than the remaining.

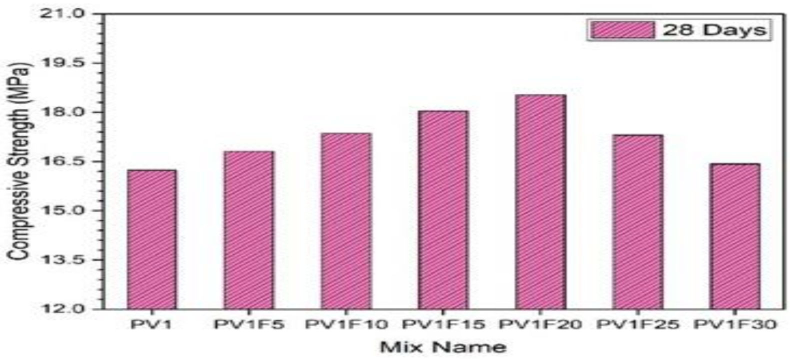

Fig.1(a) PV1 with FA

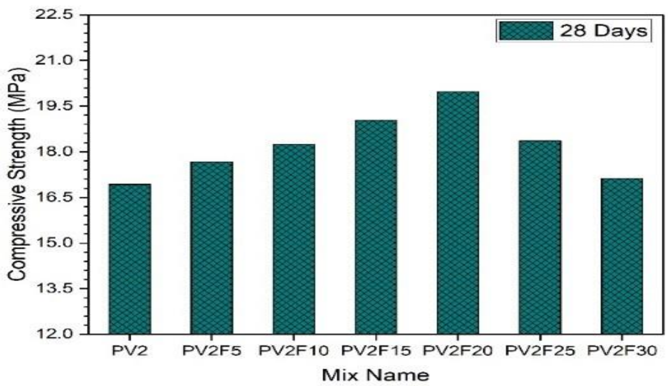

Fig.1(b) PV2 with FA

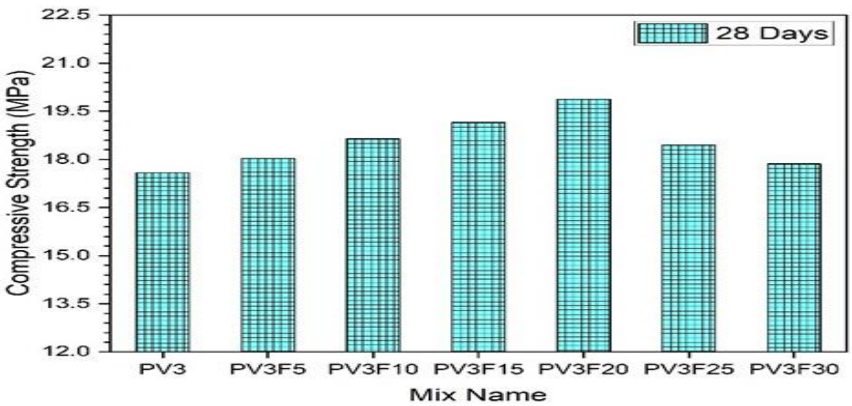

Fig.1(c) PV3 with FA

Hydraulic Properties:

Porosity:

The porosity of the pervious concrete with fly ash was presented in fig.2, In PV1 FA from 5 to 30% affected the porosity. FA in the cement improved the paste content, the enhanced paste content reduced the voids in the pervious concrete. The porosity decreased at 6.49%,10.5%,14.58%,19.48%,25.28%, and 31.85% for

5%,10%,15%,20%,25% and 30% FA levels respectively. The similar trends were observed in both PV2 and PV3 mixes with FA. However, the porosity was reduced in value with usage of 12-10mm and also by 10-4.75mm sized aggregates. In addition to the reduction of aggregate sizes in PV2 and PV3, the FA greatly affected the voids content in the pervious concrete. FA as secondary cementitious material deduced the porosity. Fig.3 and Fig.4 depicted the PV2 and PV3 mixes porosity respectively.10-4.75mmaggregated pervious concrete has17.39%lesser porosity than the16 12mm aggregated concrete at 0% fly ash. Similarly, 30% FA has about 25% lower percolation than the PV1 mix. With this, FA effected the porosity from 18% to 25% at 0 to 30% levels in cement. For PV2 mix, the change in porosity with respective to the PV1 was low compared to the relation between PV3 and PV1, which was about 5 to 8%. It may be due to the size ratio of aggregate as well as the fly ash replacement levels in cement.

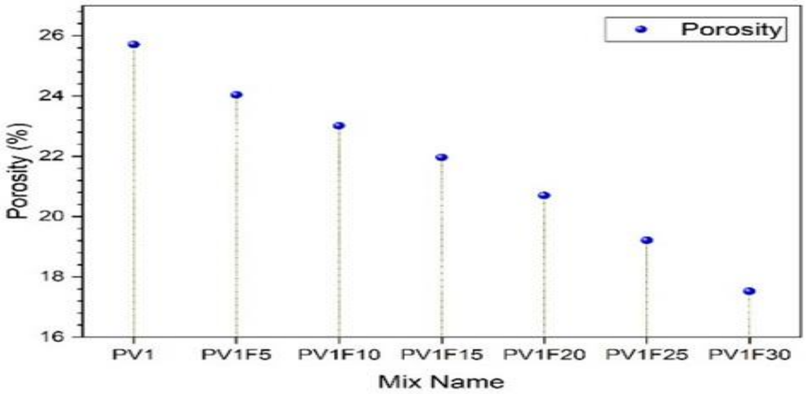

Fig.2. Porosity Vs PV1 mix

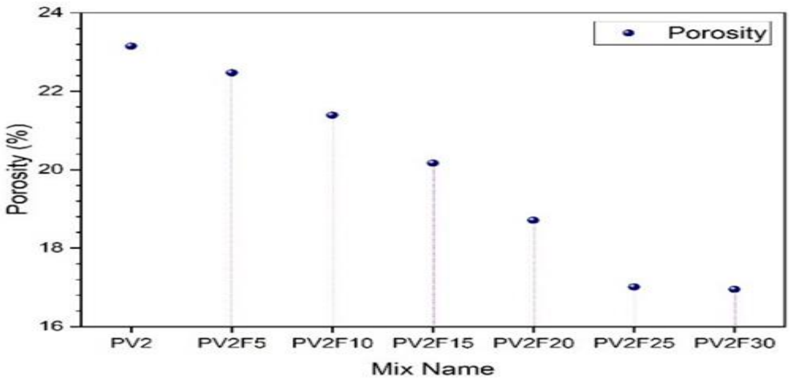

Fig.3 Porosity Vs PV2 mix

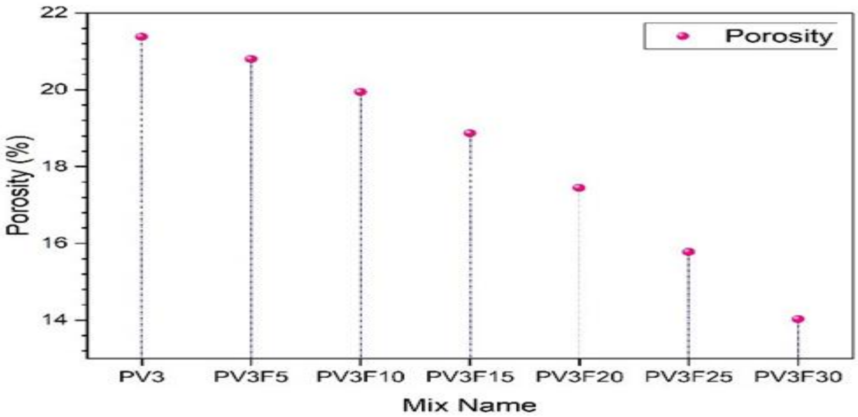

Fig.4 Porosity Vs PV3 mix

Permeability:

The permeability of the pervious concretes was tested against the variable head and also using constant head methods. It was clearly observed that the permeability of the pervious concrete varies for both the methods. However, constant head method exhibited the highest permeability than the variable head method. In the line, PV1hastheenhancedpermeability among PV2 and PV3 mixes. The coarse aggregate with 16-12mm pervious concrete has showed the top in all the mixes. Aggregate with 10-4.75mm mix exhibited the lowest permeability among all mixes. For PV1 mix, the change in permeability of both methods were varied from 10% to 20%, for PV2 has 10 to 35%, and PV3 has 25 to 45%. This may be due to the change in the aggregate size. The coarse aggregate size showed a major effect on the permeability of the pervious concrete, which was a important role for a pervious concrete. For PV2 mix there was a difference of 1.9,2.1,2.8,2.9,3.2,4.4, and 4mm/min permeability for variable head and constant head at 0,5,10,15,20,25, and 30% FA respectively. While PV1 has2.4,2.5,3.3,1.7,1.7,3.2, and 2.6mm/min for various levels of fly ash. Similarly, PV3 has 3,4.3,4.6,3.8,3.3,4.1 and 3mm/min per-culation has been observed the difference in both the methods.

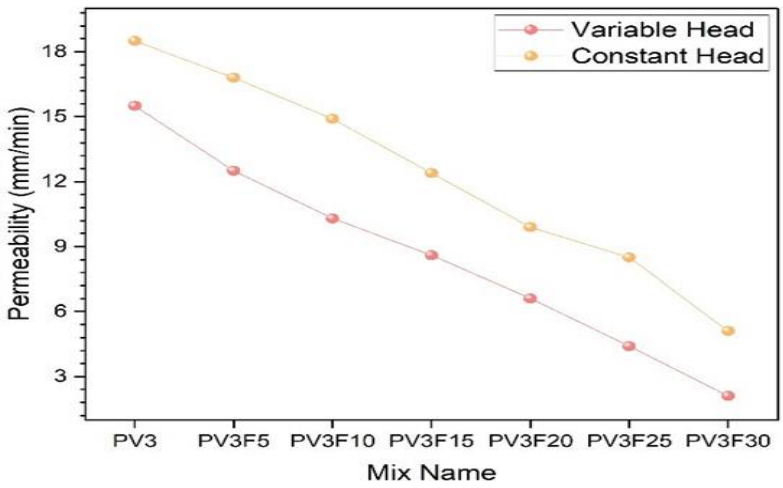

Fig.5. Permeability of PV1 mix

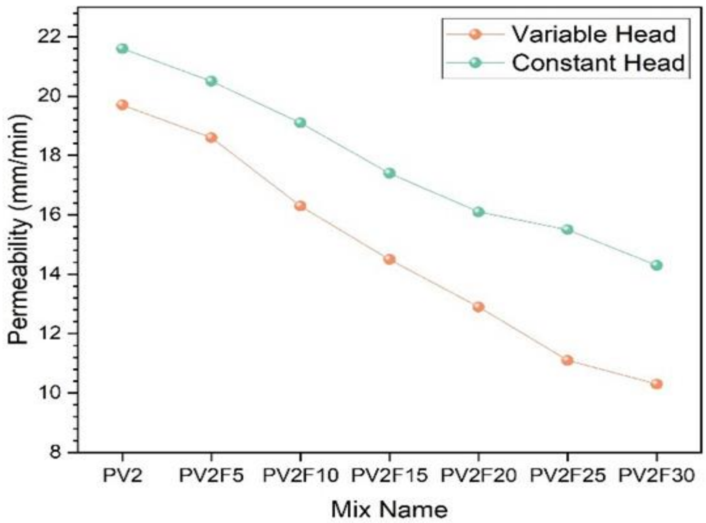

Fig.6 Permeability of PV2 mix

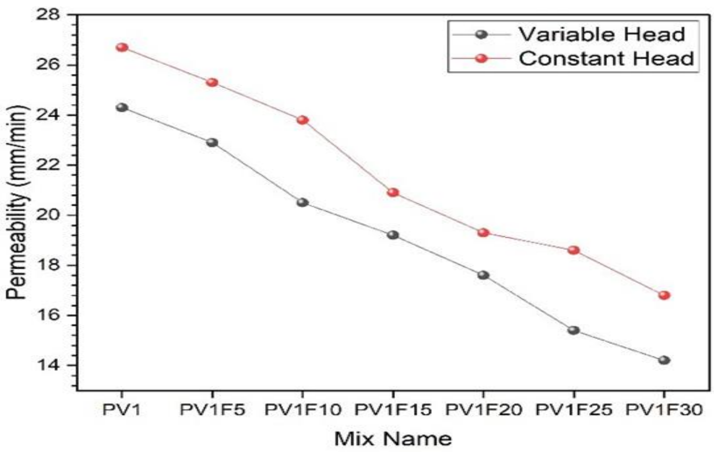

Fig.7 Permeability of PV3 mix

Conclusions

Based on the analysis and discussion of the results presented in the previous sections, the following important conclusions can be drawn.

- The mechanical properties such as compressive, splitting tensile, and flexural strengths of PC increase due to additional compaction with the Proctor hammer leading to better PC. In the same way, the density of PCs increases substantially with the increase in compacting energy. However, higher compaction is a disadvantage because higher compaction results in a substantial reduction in the permeability and porosity of the PC.
- The gradation of aggregates also has a significant effect on these properties. For a given size of aggregates, a PC having any practical range of mechanical strengths, density, and permeability can be designed by controlling the degree of compaction.
- Use of supplementary cementing materials of low grade, though reduced the mechanical strengths, the permeability and porosity have decreased significantly which further enhances the durability of the PC.
- From the present study, it is observed that using cement alone and a combination of 50% of either fly ash or GGBS can produce PCs having average compressive strength in the range of 16 to 35.5 MPa and 28.74 to 42.07 MPa at 7 and 28 days respectively. With the addition of 50% low-grade FA and GGBS, the compressive strength has decreased to an extent of 50% and 33% respectively, which saved 50% of OPC, which is quite significant from the point of waste disposal and sustainability.

Declaration

Conflict of interest:

The authors declare that this manuscript has no conflict of interest with any other published source and has not been published previously (partly or in full).

No data have been fabricated or manipulated to support our conclusions.

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